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BALLISTICS TESTS OF FIBROUS CONCRETE DOME AND PLATE SPECIMENS

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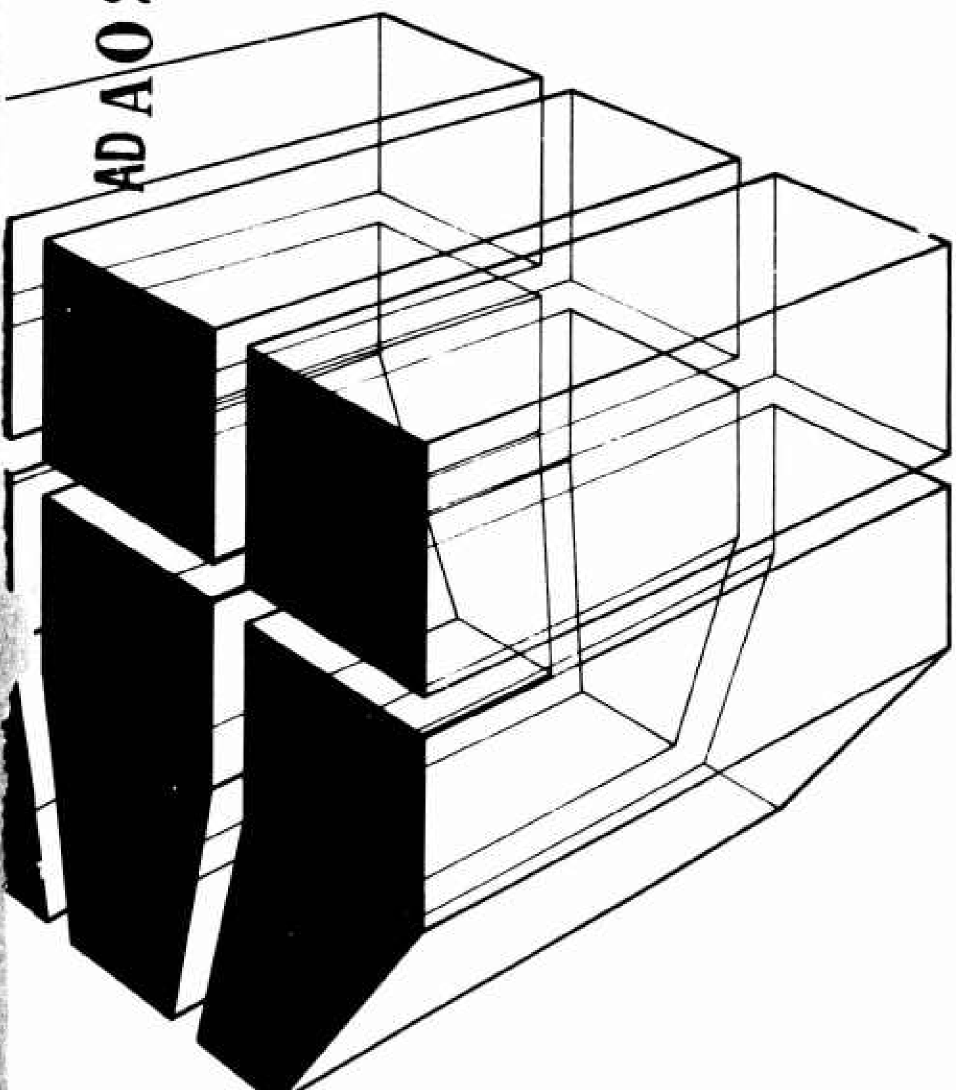

by
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Fibrous concrete plate and inflation-formed dome specimens were fabricated in the laboratory and tested to evaluate their resistance to ballistics. Variables in the investigation included: weapon system (small arms, mortars, grenades, and explosives); range (0 to 200 yds); fiber volume content (0 to 3 percent); thickness (1 to 8 in.); type of fiber reinforcement (mild steel, drawn steel, and fiberglass); and angle of incidence (0 to 75 degrees).

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Test results indicated the following: (a) the inflation-formed domes provide adequate protection from mortars and grenades detonated at ranges of 5 ft or more; (b) the specimens reinforced with fiber are far superior to those without fibers; (c) material systems of the thickness considered do not provide effective protection against demolition charges such as Composition C4; (d) resistance to penetration increases with decreased angles of impact and increased range; and (e) the specimens reinforced with the more ductile steel fibers perform slightly better than those with glass fibers.

FOREWORD

This investigation was conducted by the Construction Engineering Research Laboratory (CERL) for the Directorate of Facilities Engineering, Office of the Chief of Engineers. The work was conducted under Project 4A162719AT33, Task 01, Work Unit 001, "Research for Base Development in the Theater of Operations."

The study was performed by the Construction Materials Branch, Materials and Science Division (MS). CERL personnel directly concerned with this study were: Dr. Dan Naus, Roger Neu, David Morse, Harvey Barrett, and Kevin Ryan.

Dr. G. R. Williamson is Chief, MS, and P. A. Howdyshell is Acting Chief, Construction Materials Branch. COL M. D. Remus is Commander and Director of CERL, and Dr. L. R. Shaffer is Deputy Director.

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BALLISTICS TESTS OF FIBROUS CONCRETE DOME AND PLATE SPECIMENS

1 INTRODUCTION

Background

Fibrous concrete is ordinary concrete with the addition of discrete fibers of short length and small diameter. Fibers in general use are steel, glass, nylon, polypropylene and asbestos. Laboratory and field studies have shown that the incorporation of fibers into the concrete matrix, typically in volume percentages of 0.5 to 2.0, produces a material system with improved flexural and compressive strength and increased resistance to shock, impact, spalling, freeze-thaw, and fatigue. The Corps of Engineers is using steel fibrous concrete for pavement overlays, dam outlet channel restoration, rock slope stabilization (in the form of fibrous shotcrete), and, more recently, for construction of concrete block structures by surface bonding with glass-fiber-reinforced cement.[1]

Early studies of fibrous concrete showed that the incorporation of fibers into conventionally reinforced concrete increased the impact- and spall-resistance of the material by several hundred percent. A recent test in connection with a suppressive shield[2] structure showed that fibrous concrete with conventional reinforcement to resist the structural loading withstood 4600 psi overpressure without spalling.

Research has been underway at the U.S. Army Construction Engineering Research Laboratory (CERL) to use the impact- and spall-resistant characteristics of fibrous concrete in the construction of hardened shelters. Two systems of construction have evolved: the first employs an inflation-forming technique to produce dome shaped structures up to 15 ft in diameter and 5 ft high; the second uses inflation techniques but combines them with polyurethane foam and steel fibrous shotcrete to produce structures of various sizes and shapes. The largest structure produced to date is 18 ft in diameter and 10 ft high and was produced in only 4 hours. A 28-ft diameter dome 19 ft high is to be constructed in the next phase of the program. The domes used for the ballistic tests described in this report were constructed by the inflation-forming procedure, but both systems will be described in greater detail in Chapter 2, since the inflation/foam/shotcrete system has subsequently been proven superior. It is a very viable system for constructing hardened shelters with less engineer troop effort and reduced construction time, skill levels, and logistic requirements.

The ballistic tests described in this report were conducted to provide guidance for use of fibrous concrete in the construction of hardened structures designed to provide protection against small arms, mortars, and grenades. An evaluation of the probable resistance of fibrous concrete to enemy weapons similar to those used in these tests is also presented.

Objective

The objective of this investigation is to evaluate the resistance of fibrous concrete domes and plates to weapons typically encountered in the field.

Approach and Scope

Fibrous concrete plate and dome specimens were fabricated in the laboratory and shipped to the U.S. Army Test and Evaluation Command, Jefferson Proving Grounds, Madison, IN, for testing. Variables in the investigation included weapon type, range, fiber volume content, thickness, type of fiber used for reinforcement, and angle of incidence. The resistance to various weapons of fibrous concrete domes formed by the inflation technique was also established.

Technology Transfer Data

Manuals impacted by the data presented here include Department of the Army Technical Manual (TM) 5-855-1, *Fundamentals of Protective Design (Non-Nuclear)*, Field Manual (FM) 5-15, *Field Fortifications*, and TM 5-1300, *Structures to Resist the Effects of Accidental Explosions*. Data for possible inclusion in these manuals are summarized in Table 1. It is recommended that these data be reviewed for possible incorporation into TM 5-855-1.

Table 1 shows the steel fibrous concrete thicknesses required for complete protection from small weapons. The table also lists the weapons of the Eurasian Communist Countries (ECC) that have similar ballistic characteristics, and indicates the

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[1] G. R. Williamson, *Technical Information Pamphlet on Fibrous Concrete Overlays—Fort Hood Project*, TR M-147/ADA 015469 (Construction Engineering Research Laboratory [CERL], 1975).

[2] "Army Expanding Suppressive Shielding Technology Applications," *Army Research and Development News*, Vol 16, No. 6 (Nov-Dec 1975).

type of fibrous concrete that could be expected to provide equal protection.

Recommended design mixes and placing procedures for fibrous concrete are contained in CERL Technical Report M-147.[3]

2 WEAPON SYSTEMS AND TEST SPECIMEN FABRICATION

Weapon Systems

Four basic types of weapons were used to test the concrete specimens: small arms, mortars, grenades, and explosives.

Small Arms

The small arms used in the tests were the M16 rifle, 30-caliber machine gun, 45-caliber pistol, 50-caliber machine gun, and 20-mm automatic gun.

The M16, shown in Figure 1, is a lightweight, air-cooled, gas-operated, magazine-fed rifle designed for automatic or semiautomatic fire. Muzzle velocity of the projectile is approximately 3,250 fps. The rifle has a maximum range of 2,653 m and a maximum effective range of 460 m. Ball ammunition (M193) was used.

The M73 30-caliber (7.62 mm) machine gun, shown in Figure 2, operates by recoil with gas assist and is air cooled. Muzzle velocity of the projectile is 2,750 fps with a maximum range of 3,800 m and an effective range of 800 m. Ball ammunition (M80) was used.

Figure 3 shows the 45-caliber pistol, which operates by recoil and is air cooled. The projectile's muzzle velocity is 855 fps. The pistol has a maximum range of 1,500 m and a maximum effective range of 40 m. Ball ammunition (M1911) was used.

The 50-caliber machine gun, shown in Figure 4, operates by recoil and is air cooled. Muzzle velocity of the projectile is 2,910 fps. The gun has a maximum range of 6,800 m and a maximum effective range of 1,500 m. Ball ammunition (M33) was used.

Figure 5 illustrates the 20-mm automatic gun, which has a maximum range of 7,200 m and an effective fighting range of 1,500 m. Muzzle velocity of the projectile is 3,380 fps. The ammunition used was M221.

Mortars

The 81-mm mortar used is shown in Figure 6. The mortar (HE374A2), equipped with an M524 fuze, contained a pearlitic malleable-iron projectile loaded with approximately 2.1 lb of Composition B. The total mortar weight was approximately 9.3 lb. The mortar has a minimum range of 72 m, a maximum range of 4,737 m, and an effective bursting area diameter of 34 m. The mortar rounds were statically detonated.

Grenades

M67 fragmentation grenades with M213 fuzes, shown in Figure 7, were used. The grenades had a spherical body approximately 2.5 in. in diameter, contained 6.5 oz of Composition B, and had a total weight of 14 oz. They detonated 4 to 5 seconds after release of the safety lever. The maximum range of the grenades is approximately 35 m.

Explosives

Composition C4, supplied in blocks approximately 11 × 2 × 1 in. was the explosive. The desired weight of explosive was obtained by dividing the blocks. The approximate velocity of detonation for Composition 4 is 8,040 m/sec. The effectiveness of Composition C4 relative to TNT (base = 1.00) is 1.34.

Fibrous-Concrete Test Specimen Fabrication

Dome Fabrication

Three inflation-formed fibrous-concrete domes were fabricated by placing a predetermined thickness* of fibrous concrete† on the lower membrane, screening and compacting the concrete, and then placing the upper membrane on the fibrous

[3] G. R. Williamson, *Technical Information Pamphlet on Fibrous Concrete Overlays—Fort Hood Project*, Technical Report M-147/ADA015469 (CERL, 1975).

*Initial preinflated fibrous concrete thicknesses for the three domes were approximately 3, 4.5, and 6 in.

†Mix proportions per cubic yard of concrete were: 8 bags of cement, 2,260 lbs of sand, 750 lbs of ⅜ in. gravel, 200 lbs of steel fibers (1.5 percent by volume), and sufficient water to provide a slump of 2 to 3 in. (typically, about 380 lbs of water). Fifteen ounces of retarder per sack of cement were added to the mix water to delay the concrete's initial set.

concrete and anchoring it. Compressed air (at low pressure and high volume) was then applied to lift the membranes and material system to the desired rise of one-third the dome diameter. The surface was then vibrated to heal tears which developed because the surface area of the fibrous concrete was approximately doubled. The dome rise was maintained constant for 24 hours until the fibrous concrete gained sufficient strength to support itself. The air supply was then stopped, the upper membrane was removed, and the domes were lifted from the ring beam to a storage area. A detailed description of the procedure for inflation forming is presented in CERL Interim Report M-115.[4]

The three domes were shipped from CERL to Jefferson Proving Grounds for testing. To simplify transportation, a vertical section 2 ft from the edge of each dome was removed with a demolition saw to reduce the dome's width from 10.5 ft to 8.5 ft. Figure 8 shows the domes at Jefferson Proving Grounds prior to testing.

A new inflation/foam/shotcrete system recently developed at CERL has proven superior to the inflation system and will be used subsequently for all structures of this type. This system is capable of producing 18 ft diameter × 10 ft high hemispherical domes in 4 hours. The steps involved are as follows:

1. An elastic membrane is inflated to a predetermined height

2. The membrane is coated with 3 to 5 in. of polyurethane foam

3. The foam is sprayed with steel fibrous shotcrete to the thickness required for the intended use.

Domes 15 and 18 ft in diameter have been successfully produced by this system and domes up to 100 ft in diameter are considered feasible. These domes can be temporary or permanent, conventional or hardened, and are relocatable. They can be buried or covered with sand bags for added protection. When the domes are unprotected, the steel fibrous concrete and shotcrete provide good resistance to penetration of small arms fire and resistance to spalling from fragment impact.

[4] G. Batson, *Inflation Forming of Steel Fiber-Reinforced Concrete Domes*, Interim Report M-115 (CERL, 1974).

Plate Fabrication

Fibrous-concrete plate specimens 12-in. square and ranging in thickness from 1 to 6 in. were fabricated to evaluate the resistance of fibrous concrete to small arms. Companion plate specimens 24-in. square and with thicknesses ranging from 2 to 4 in. were fabricated to evaluate the resistance to explosive charges.

The plate specimens were cast in plywood molds. The mix proportions per cubic yard of concrete were: 8 bags of Type III cement; 1,500 lbs of sand; 1,500 lbs of $^3/_8$ in. gravel; 300 lbs of water containing 10 oz of water reducer per sack of cement; and fiber volume contents of 0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 percent. The molds were filled in three lifts and the concrete was compacted by external vibration. Compressive strength and splitting tensile strength properties of the mixes are presented in Table 2.

3 EXPERIMENTAL INVESTIGATION AND RESULTS

The experiments were designed to evaluate the protection that fibrous concrete offers against conventional weapons. Variables in the investigation included weapon type (small arms, mortars, grenades, and explosives); range (0 to 200 yd); fiber volume content (0 to 3 percent); thickness (1 to 6 in.); type of fiber used for reinforcement (mild steel, drawn steel, and fiberglass); and angle of incidence (0 to 75 degrees). Test specimens used in the investigation were the inflation-formed fibrous-concrete domes and the plate specimens both with and without fiber reinforcement, as described in Section 2.

Dome Tests

The domes were tested to evaluate their resistance to grenades, mortars, Composition C4 explosives, and small arms. To test the domes under the most severe conditions, no cover was placed on them. The results of the dome tests are summarized in Table 3.

Grenade Tests

M67 fragmentation grenades with M213 fuzes were statically detonated at distances from 0 to 15 ft from the 3-in.-thick dome and at various positions adjacent to the 6-in. dome. Damage from grenade detonations 15, 10, and 5 ft from the 3-in. dome is shown in Figure 10. Figure 11 shows the damage after detonation of a grenade at the surface of the dome. Detonation of a grenade inside the dome produced the damage shown in Figure 12.* Locating grenades at sections of the dome which were thinner than the base resulted in complete penetration.

The dome having a nominal thickness of 6 in. was tested with the grenades placed only on the surface at points where the thickness was less than 4 in. There was complete penetration in every case. Where the thickness exceeded 4 in., only spalling† occurred.

Detonating grenades at distances of approximately 5 ft or more did not produce penetration or spalling. Complete penetration resulted when detonation occurred adjacent‡ to a point on the dome where the thickness was less than 4 in. In contrast, only slight scabbing and spalling resulted when the detonation occurred at a point on the surface where the thickness was greater than 4 in.

Mortar Tests

M374A2 81-mm mortar rounds were statically detonated at distances from 0 to 15 ft from the 6-in. dome. The mortar rounds were positioned as shown in Figure 9 so that the angle between a horizontal plane and the longitudinal axis of the mortar round was between 45 and 60 degrees, simulating the normal angle of mortar arrival. At each detonation distance two mortar rounds were detonated: one pointed toward the dome, followed by a second round oriented perpendicular to the direction of dome. The cumulative damage from these mortar detonations at 5, 10, and 15 ft is shown in Figure 13.

In general, detonations of the mortar rounds at distances greater than 5 ft produced scabbing and only slight spalling of material from the 6 in. dome; i.e., the uncovered dome appeared to provide adequate protection against mortar rounds detonated 5 ft or more from the dome. Detonation of mortar rounds adjacent to the dome's surface, pointed either toward or parallel to the surface, resulted in catastrophic failure of the dome.

*During the test, the dome was supported on four 4 × 4 in. wood blocks, allowing part of the pressure buildup from the grenade detonation to escape under the dome. In an actual situation the pressure would be released primarily through the entrance, so the force applied would be greater and would result in more severe damage to the crown of the dome.

†Spalling is the disruption or throwing of material from the rear of the target as a result of impact, explosion, or both, on the opposite face. Scabbing is the disruption or throwing of material from the front of the target as a result of either impact, explosion, or both, at the front face.

‡Detonation of a grenade at the surface of a dome is improbable, since the grenade would have to detonate precisely as it reaches the dome's surface. It is more likely that the grenade would bounce off the dome and detonate at a distance.

Composition C4 Explosives

Composition C4 charges ranging from approximately ⅛ to ½ lb were detonated adjacent to the outer surface of the 3-in. dome near its base. Figure 14 shows the location of ⅛ lb of Composition C4, and Figure 15 presents the damage resulting from the detonation. The positioning and damage resulting from a ¼-lb charge are shown in Figures 16 and 17, respectively.

Spalling and scabbing of the 3-in. dome resulted from Composition C4 charges as small as ⅛ lb. The visible effects (structural damage) resulting from explosion of C4 charges of ¼ lb to ½ lb did not increase noticeably with the size of charge, probably because the energy produced from the C4 explosion appeared to be localized and went into punching a hole through the structure and expelling the material. Dome thicknesses in excess of 3 to 4 in. are required to provide adequate protection against a C4 charge as small as ⅛ lb. In general, the uncovered fibrous-concrete domes will not provide adequate protection against demolition charges such as Composition C4.

Small Arms

Figure 18 shows the 4-½-in. dome and the segment of the 6-in. dome* used to evaluate the resistance of the structures to small arms weapons; i.e., a 50-caliber machine gun and a 20-mm automatic gun. The range from weapon to target was 200 yds. Ball ammunition was used with the 50-caliber machine gun, and both inert and high-explosive ammunition were used with the 20-mm automatic gun.

The results of firing the 50-caliber machine gun at the 4-½-in. dome several times are shown in Figure 19. Complete penetration of the dome occurred at all impact points, which ranged from approximately 1 ft above the base of the dome to the crown. Figure 20 shows the effects of the 50-caliber machine gun on the segment of 6-in. dome. Complete penetration of the dome did not occur, although some spalling resulted from shot numbers 2, 3, and 4. Approximate dome thicknesses at shot 2 and shot 7 were 6 in. and 3 in., respectively.

*The dome segment was supported so that its orientation simulated the position it would have had if the entire dome were intact.

Inert rounds from the 20-mm automatic gun completely penetrated the 4-½-in. dome. They also penetrated the 6-in. dome segment near its crown, where the thickness was 3 in., but did not completely penetrate near the 6-in.-thick base. Repeated firings of inert rounds penetrated the dome segment and destroyed its structural integrity. The effects of 20-mm high-explosive rounds on the 4-½-in. dome and the 6-in. dome segment did not appear to be as severe as those of the inert rounds. This effect may have resulted from dissipation of a significant portion of the energy in deforming the projectile and spalling the fibrous concrete.

Plate Tests

Plate specimens 2 ft square and with thicknesses of 2, 3, and 4 in. were fabricated to evaluate the resistance of fibrous concrete (1.5 percent by volume of chopped steel fiber) to Composition C4 explosives.

Composition C4

Composition C4 charges were detonated at the surface of the plate specimens. The plate specimens were simply supported on 4 × 4 in. blocks of wood, as shown in Figure 21. The variables in the tests were the size of Composition C4 charge and the composite thickness of plate.

Figures 22a and 22b present the front and rear surfaces of a 4-in. fibrous concrete plate subjected to a ⅛-lb charge of Composition C4. The effects of ¼ lb of Composition C4 on plates having composite thicknesses ranging from 2 to 8 in. in 1 in. increments are presented in Table 3. Figure 23 shows the donor and acceptor sides of a 6-in. plate that was subjected to a ¼-lb charge of C4.

Spalling and cracking of the concrete plates occurred in all tests. Approximately 4 in. of fibrous concrete was required to resist complete penetration from a single detonation of a ⅛-lb charge of Composition C4, and approximately 6 in. of fibrous concrete was required to prevent complete penetration from a ¼ lb charge.* In general, the effectiveness of the Composition C4 decreased with increasing composite thickness of the specimens, as is readily apparent from the data in Table 3.

*These tests represent a slightly more severe condition than would be encountered in a fibrous concrete structure because of the limited size of the plate specimens and the resultant edge effects.

Small Arms

The resistance of fiber-reinforced and unreinforced concrete to small arms was evaluated by testing 12-in. square plate specimens. Specimen parameters included geometry (thicknesses from 1 to 6 in.), fiber volume content (from 0 to 3 percent), and type of fiber (mild steel, drawn steel, or fiberglass). Angles of projectile impact* ranged from 15 to 90 degrees. The distance of fire ranged from 10 to 200 yds. The small arms weapons used were the M16 rifle, M73 30-caliber machine gun, 45-caliber pistol, 50-caliber machine gun, and 20-mm automatic gun.

• M16 Rifle. The test fixture for securing the specimens and varying the angle between the trajectory of the projectile and the plane of the specimen is shown in Figure 24 with a specimen in position. The tests were conducted at ranges of 50, 100, 150, and 200 yds, with the majority conducted at 100 yds. Unless otherwise noted, the results presented are for a range of 100 yds. Results for all the M16 tests are summarized in Table 4.

The effect of fiber volume content on material performance was evaluated by testing plate specimens having thicknesses of 2, 3, and 4 in. with fiber volume contents from 0 to 3 percent. Figures 25a, b, c, d, e, and f present the results for plate specimens reinforced with 0, 1, 1.5, 2, 2.5, and 3 percent chopped steel fibers, respectively. The figures indicate only a very slight trend toward a decrease in depth of penetration with increase in fiber content. When complete penetration did not occur, the depth of penetration appeared to be independent of thickness for a given fiber content. A comparison of scabbing occurring in 2-in. plates with fiber contents from 0 to 3 percent is shown in Figure 26. The increase in fiber content reduced the amount of scabbing. Depths of penetration for various specimen thicknesses and fiber contents are presented in Table 5.

Figures 27a, b, c, and d present the results for plate specimens 2-, 3-, and 4-in. thick which were unreinforced, reinforced with 1.5 percent chopped steel, with 1.5 percent drawn steel, and with 1.5 percent fiberglass fibers, respectively. The figures indicate that the addition of fibers reduced the depth of

*The angle of impact is the angle between the trajectory of the projectile and the plane of the specimen. The angle of impact was varied by changing the orientation of the specimens. No corrections were made for loss of elevation by the projectile during flight.

penetration. Penetration depths for the three types of fiber were similar; however, in tests where more than one projectile was fired at a plate, the more ductile steel fibers performed better than the fiberglass fibers. A comparison of scabbing for 2-in. fiber-reinforced and unreinforced plates is presented in Figure 28. Table 6 summarizes depths of penetration for each type of fiber and specimen thickness.

Varying the angle of impact between the projectile and the plane of the chopped-fiber-reinforced specimen showed that the depth of penetration increased with the angle of impact. Thicknesses in excess of those required to prevent complete penetration did not reduce the depth of penetration but did improve the ability of the section to survive several impacts. Table 7 summarizes the depths of penetration for the angles of impact and thicknesses investigated.

The effect of range was evaluated for plates containing either 0 or 1.5 percent chopped steel fiber reinforcement for ranges of 50, 100, 150, and 200 yds. In general, the addition of fibers reduced the depth of penetration, and the depth of penetration decreased with an increase in range. Table 8 summarizes the results.

• 30-Caliber Machine Gun. Parameters for the 30-caliber machine gun were the same as for the M16 rifle. Table 4 summarizes the results.

Figures 29a, b, c, d, e, and f present the results for 2-, 3-, and 4-in. plate specimens reinforced with 0, 1, 1.5, 2, 2.5 and 3 percent chopped steel fibers, respectively. Data trends similar to those for the M16 rifle were obtained. The thickness required to resist complete penetration of the 30-caliber projectile was 4 in. for the unreinforced specimens and 3 in. for the fiber-reinforced specimens. Figure 30 presents a comparison of scabbing for 3 in. specimens containing fiber contents from 0 to 3 percent. (Shown for the fiber-reinforced plates are the effects of two 30-caliber projectile impacts.) Table 9 summarizes penetration depths for various thicknesses and fiber contents.

The results for plate specimens of 2-, 3-, and 4-in. thicknesses, containing no fibers, 1.5 percent chopped steel, 1.5 percent drawn steel, and 1.5 percent glass fibers showed data trends similar to those for the M16 rifle. Figure 31 shows scabbing of four 3-in. plates which contained no fibers, 1.5 percent chopped steel, 1.5 percent drawn steel, and 1.5 percent fiberglass. The differing amount of scabbing indicates that the more ductile fibers produced improved performance. Table 10 presents penetration depths as a function of fiber type and specimen thickness.

Variations in the impact angle between the 30-caliber projectile and the plane of the chopped-steel fiber-reinforced plate specimens showed data trends similar to those for the M16 plate tests. Table 11 presents penetration depths as a function of thickness and impact angle.

The effect of range resulted in data trends similar to those for the M16. Depths of penetration as a function of thickness and range for unreinforced and fiber-reinforced plates are presented in Table 12.

• 45-Caliber Pistol. The parameter investigated for the 45-caliber pistol was the chopped-steel fiber content; specimens without fibers and with 2.5 percent fiber content were tested. Table 4c summarizes the results. In general the 45-caliber projectile was very ineffective against either plain or fiber-reinforced plate specimens.

• 50-Caliber Machine Gun. Parameters investigated for the 50-caliber machine gun were the same as for the M16 rifle and the 30-caliber machine gun. Table 4d summarizes the results.

The effect of fiber content on resistance to penetration is presented in Figures 32a, b, c, d, e, and f for plate specimens containing 0, 1, 1.5, 2, 2.5, and 3 percent chopped steel fibers, respectively. All plates tested were completely penetrated. However, the degree of plate fragmentation decreased as the fiber volume increased. Table 13 summarizes penetrations for various thicknesses and fiber contents.

The plate specimens containing no fiber, 1.5 percent chopped-steel, 1.5 percent drawn-steel, and 1.5 percent fiberglass fibers were all penetrated. As noted previously, however, the plates containing the more ductile steel fibers provided superior resistance to fragmentation as compared to the fiberglass-reinforced plates and the unreinforced plates. Table 14 summarizes penetrations as a function of fiber type and plate thickness.

The effects of varying the impact angle between the 50-caliber projectile and the plane of the plates reinforced with 1.5 percent chopped steel fiber showed that, in general, the plate thickness required to resist penetration or prevent scabbing increased with the impact angle. Depths of penetration as a function of angle of impact and plate thickness are summarized in Table 15.

The effect of range on resistance to penetration was determined for ranges of 50, 100, 150, and 200 yds. No data trends were identified from these results except that for a 90-degree angle of impact a plate thickness in excess of 6 in. was required to resist complete penetration. Table 16 summarizes penetration depths as a function of range and specimen thickness.

• 20-mm Automatic Gun. Parameters investigated for the 20-mm automatic gun were very limited because of the effectiveness of the weapon and the small number of plate specimens remaining. Table 4 presents the results of the gun tests. Figure 33 shows the effects of the weapon on a 5-in. chopped-steel fiber-reinforced plate tested at 200 yds. The result for a 2-in. chopped-fiber-reinforced plate and a similar 3-in. plate with a 4-in. air space between the plates is presented in Figure 34. Figure 35 shows the results of a 4-in. chopped-fiber-reinforced plate tested at a range of 200 yds and an impact angle of 45 degrees. These results, although limited, indicate that fiber-reinforced plate specimens with a thickness greater than 6 in. are required to prevent complete penetration of the 20-mm projectile.

4 CONCLUSIONS

Inflation-Formed Dome Tests

Three inflation-formed fibrous-concrete domes with fibrous concrete thicknesses prior to inflation of 3, 4.5 and 6 in. were evaluated to establish their resistance to grenades, mortars, Composition C4, and small arms (50-caliber machine gun and 20-mm automatic gun). The following conclusions may be drawn from this phase of the investigation:

• Transportation of the 10.5-ft diameter domes using conventional means presents no problems.

• The domes provide adequate protection from fragments from grenades detonated 5 ft or more from the dome.

• Dome thicknesses in excess of 4 in. are required to prevent penetration by fragments from grenades detonated adjacent to the dome's surface.

• Dome thicknesses in excess of 1 in. at the crown are required to prevent severe structural damage to the dome from a grenade detonated internally.

• The domes provided adequate protection from fragments of mortar rounds detonated 5 ft or more from the dome.

• Dome thicknesses in excess of 4.5 in. are required to prevent extensive structural damage to the domes from a mortar round detonated adjacent to the dome.

• Dome thicknesses in excess of 4 in. are required to prevent scabbing from a Composition C4 charge as small as 1/4 lb. In general the uncovered fibrous concrete domes do not provide adequate protection against demolition charges.

• The 6-in. dome provides adequate protection against a 50-caliber machine gun for a limited number of firings; however, several projectiles impacting in the same region will penetrate the dome.

• The uncovered domes tested did not provide adequate protection against 20-mm automatic gun projectiles.

• The effectiveness of the dome's resistance to ballistics increased with the thickness of the dome.

Plate Tests

Plate specimens 2 ft square with thicknesses of 2, 3, and 4 in. were fabricated to evaluate the resistance of concrete reinforced with 1.5 percent chopped steel fiber to Composition C4 charges. The resistance of fibrous concrete to small arms was determined by fabricating and testing plate specimens 1 ft square with thicknesses ranging from 2 to 6 in. in 1-in. increments. Conclusions which can be drawn from the plate tests are as follows.

• Fibrous-concrete thicknesses of at least 4 in. are required to resist a 1/8-lb charge of Composition C4, and in excess of 6 in. of fibrous concrete is required to resist penetration of a 1/4-lb charge.

• The relative magnitude of fragmentation—and probably the velocity of spalled particles—resulting from demolition charges or impact by small arms projectiles was significantly reduced by incorporating fibers into the concrete matrix.

• Resistance of the fiber-reinforced specimens to projectile penetration was generally superior than that of the unreinforced specimens.

- The effectiveness of specimens in resisting penetration is directly proportional to specimen thickness and inversely proportional to the energy of the projectile. Thicknesses in excess of that required to resist complete penetration do not reduce the depth of penetration, but they do increase the ability of the specimens to survive more than one impact.

- The effectiveness of the specimens in resisting penetration by small arms projectiles was directly proportional to range.

- As the angle of impact between the projectile and the plane of the specimen increased, the effectiveness of the projectile increased.

- The resistance to fragmentation (shattering) of the ductile-steel fiber-reinforced specimens was superior to that of the fiberglass-reinforced specimens. The fiberglass- and the steel-reinforced specimens were both superior to the unreinforced specimens.

- The resistance to penetration by small arms projectiles was slightly improved by increasing the quantity of fibers per volume of concrete matrix. The quantity of scabbing and the affected zone of material decreased as the fiber quantity increased.

- Fiber-reinforced plate specimens demonstrated a superior ability to survive repeated projectile impacts.

- The results obtained identify the minimum thickness required for the fibrous-concrete domes to resist complete penetration by various small arms. For example, assuming a horizontal trajectory, the dome thickness at various locations along a line from the base to the crown required to resist a specific weapon system may be estimated by relating the results from the angle-of-impact plate tests to a corresponding location in the dome. The maximum and minimum thickness required may be estimated from impact angles of 90 and 15 degrees, respectively.

Future Work

All future work will use the inflation/foam/steel fiber shotcrete system. The construction of a dome structure 28 ft diameter, 14 ft high is in the planning stage. Structures other than dome shapes are scheduled for future work. Adaptation of the system to field fortifications and to other specific needs of the user will be considered as they are identified. Additional ballistic studies will be undertaken to provide a complete characterization of the protection provided by steel fibrous shotcrete. A demonstration using field Army personnel will be conducted.

Table 1

Protection Offered by Steel Fibrous Concrete Against Small Arms Fire

Minimum Required Thickness, in. (mm)	Volume Percent of Steel Fibers	Cartridge USA ECC*	Bullet Model	Bullet Weight, Grams	Muzzle Velocity, fps (mps)	Estimated Effective Range, ft (m)	Minimum Range for Protection, yd (m)	Penetration at 90° Impact Angle, in. (mm)	Remarks
3(76)	1.5	5.6x45 mm (M16)	M193, Ball	3.6	3250 (990)	1510 (460)	50 (46)	0.9 (23)	No scabbing (spalling) on acceptor side
4(102)	1.5	7.62x51 mm (NATO)	M80, Ball	9.6	2750 (835)	2625 (800)	50 (46)	1.3 (33)	No scabbing (spalling) on acceptor side
		7.62x39 mm (ECC)	Ball, PS	7.9	2410 (735)	1315 (400)	50 (46)		
		7.62x54 mm (ECC)	Ball, LPS	9.6	2820 (860)	3280 (1000)	50 (46)		
1(25)	2.5	Caliber .45	M1911, Ball	15.2	855 (260)	130 (40)	10 (9)	0.1 (3)	No scabbing (spalling) on acceptor side
6(152)	1.5	81 mm	Mortar	954, Comp B	— —	112 (34)	1.7 (1.5)	—	No scabbing (spalling) on acceptor side
		82 mm	Mortar, Frag V08320U	440, TNT, DNT	— —	66 (20)	1.7 (1.5)	—	
3(76)	1.5	M67	Hand Grenade	184, Comp B	— —	112 (34)	1.7 (1.5)	—	No scabbing (spalling) on acceptor side
			Hand Grenade, Model F-1	50, TNT	— —	66 (20)	1.7 (1.5)	—	

*ECC—Eurasian Communist Countries. Weapons shown are Soviet type, but are made throughout ECC.

Note—Ballistics data for both U.S. and foreign weapons were obtained from the U.S. Army Foreign Science and Technology Center.

Table 2

Properties of Concrete Mixes

Fiber Content, v_f Vol %	Type of Fiber Reinforcement*	Compressive Strength, f_c, ksi	Splitting Tensile Strength, f_t, ksi
0	None	9.50	0.68
1.0	CS	10.30	—
1.5	CS	11.08	1.17
2.0	CS	11.90	1.60
2.5	CS	11.60	1.72
3.0	CS	13.20	1.86
1.5	FG	3.90	—

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel.
FG denotes 1 in. fiberglass fibers from Owens-Corning.

Table 3

Dome Test Results

Weapon	Test Specimen	Fiber and Vol %	Proximity	Results
M67 grenade	3 in. dome	Steel (1.5)	15 ft	Slight pitting
M67 grenade	3 in. dome	Steel (1.5)	10 ft	Slight pitting
M67 grenade	3 in. dome	Steel (1.5)	5 ft	Slight pitting
M67 grenade	3 in. dome	Steel (1.5)	0 ft	Complete penetration
M67 grenade	6 in. dome	Steel (1.5)	0 ft	Complete penetration for $t < 4$ in. Scabbing for $t > 4$ in. where t is the thickness
81-mm mortar	6 in. dome	Steel (1.5)	15 ft	Slight pitting
81-mm mortar	6 in. dome	Steel (1.5)	10 ft	Slight pitting
81-mm mortar	6 in. dome	Steel (1.5)	5 ft	Slight pitting
81-mm mortar	6 in. dome	Steel (1.5)	0 ft	Failure of dome
Composition C4				
1/8 lb	3 in. dome		0 ft	Spalling and scabbing
1/4 lb	3 in. dome		0 ft	Complete penetration
1/2 lb	3 in. dome		0 ft	Complete penetration
50-caliber machine gun	4½ in. dome	Steel (1.5)	200 yd	Complete penetration at all impact points 1 ft above base of dome
50-caliber machine gun	6 in. dome	Steel (1.5)	200 yd	Scabbing
20-mm (inert)	4½ in. dome	Steel (1.5)	200 yd	Complete penetration
20-mm (inert)	6 in. dome	Steel (1.5)	200 yd	Penetration for $t < 3$ in. no penetration for $t = 6$ in.
Composition C4 2 × 2 ft plates				
1/8 lb	4 in. thick	Steel (1.5)	0	Penetration 1.25 in. plate intact
1/4 lb	2 in. thick	Steel (1.5)	0	Complete penetration
1/4 lb	3 in. thick	Steel (1.5)	0	Complete penetration
1/4 lb	4 in. thick	Steel (1.5)	0	Complete penetration
1/4 lb	5 in. thick	Steel (1.5)	0	Complete penetration
1/4 lb	6 in. thick	Steel (1.5)	0	Plate shattered but not completely penetrated
1/4 lb	7 in. thick	Steel (1.5)	0	Plate shattered but not completely penetrated
1/4 lb	8 in. thick	Steel (1.5)	0	Plate shattered but not completely penetrated

Table 4a

M16 Rifle Plate Test Results

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees)	Depth of Penetration (in.)	Comments
50	2	1.5 CS	90	1.0	Slight scabbing
50	3	1.5 CS	90	0.9	No scabbing
50	4	1.5 CS	90	0.9	No scabbing
50	2	None	90	2.0	Scabbing
50	3	None	90	1.1	No scabbing—cracked through
50	4	None	90	1.0	Cracked through
50	5	None	90		No scabbing
100	2	None	90	2.0	Scabbing
100	3	None	90	0.7	Cracked through
100	4	None	90	1.1	No scabbing
100	2	1.5 FG	90	0.9	Scabbing—cracked through
100	3	1.5 FG	90	1.0	No scabbing
100	4	1.5 FG	90	1.1	No scabbing
100	2	1.5 DS	90	1.0	Cracked through
100	3	1.5 DS	90	0.9	No scabbing
100	4	1.5 DS	90	0.9	No scabbing
100	2	1.5 CS	90	0.9	Slight crack through
100	3	1.5 CS	90	0.9	No scabbing
100	4	1.5 CS	90	0.8	No scabbing
100	2	1.0 CS	90	0.9	Scabbing
100	3	1.0 CS	90	0.9	No scabbing
100	4	1.0 CS	90	0.9	No scabbing
100	2	2.0 CS	90	1.0	Slight crack through
100	3	2.0 CS	90	0.8	No scabbing
100	4	2.0 CS	90	0.9	No scabbing
100	2	2.5 CS	90	0.8	Slight crack through
100	3	2.5 CS	90	0.7	No scabbing
100	4	2.5 CS	90	0.8	No scabbing
100	2	3.0 CS	90	0.8	Slight crack through
100	3	3.0 CS	90	0.8	No scabbing
100	4	3.0 CS	90	0.7	No scabbing
100	1	1.5 CS	15	0.1	No scabbing
100	1	3.0 CS	15	0.3	No scabbing
100	1	1.0 CS	30	0.4	Slight Crack through
100	1	1.5 CS	30	0.4	Scabbing—cracked through
100	1	2.0 CS	30	0.5	Scabbing—cracked through
100	1	2.5 CS	30	0.4	Slight scabbing
100	1	3.0 CS	30	0.5	Slight scabbing
100	2	1.5 CS	30	0.4	No scabbing
100	3	1.5 CS	30	0.3	No scabbing
100	2	1.5 CS	45	0.6	No scabbing
100	3	1.5 CS	45	0.6	No scabbing
100	4	1.5 CS	45	0.6	No scabbing
100	2	1.5 CS	60	0.7	Slight crack through
100	3	1.5 CS	60	0.6	No scabbing
100	4	1.5 CS	60	0.8	No scabbing

Table 4a (Cont)

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees)	Depth of Penetration (in.)	Comments
100	2	1.5 CS	75	0.8	Slight crack through
100	3	1.5 CS	75	0.9	No scabbing
100	4	1.5 CS	75	0.9	No scabbing
150	2	None	90	2.0	Scabbing—cracked through
150	3	None	90	0.7	Cracked through
150	1	1.5 CS	90	1.0	Scabbing
150	2	1.5 CS	90	0.9	No scabbing
150	3	1.5 CS	90	0.8	No scabbing
200	2	None	90	0.8	No scabbing
200	3	None	90	0.8	No scabbing
200	2	1.5 CS	90	0.6	No scabbing
200	3	1.5 CS	90	0.8	No scabbing

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel. DS denotes 1.016 x 1 in. drawn steel fibers from National Standard. FG denotes fiberglass fibers from Owens-Corning.

Table 4b

30-Caliber Machine Gun Plate Test Results

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees)	Depth of Penetration (in.)	Comments
50	2	1.5 CS	90	2.0	Cracked through
50	3	1.5 CS	90	1.2	Cracked through
50	4	1.5 CS	90	1.3	No scabbing
50	2	None	90	2.0	Scabbing
50	3	None	90	3.0	Scabbing
50	4	None	90	1.3	Cracked through
50	5	None	90	1.3	Cracked through
100	2	None	90	2.0	Scabbing
100	3	None	90	3.0	Scabbing
100	4	None	90	1.3	Cracked through
100	5	None	90	1.3	No scabbing
100	2	1.5 FG	90	2.0	Scabbing
100	3	1.5 FG	90	1.4	No scabbing
100	4	1.5 FG	90	1.3	No scabbing
100	2	1.5 DS	90	2.0	Scabbing
100	3	1.5 DS	90	1.2	Cracked through
100	4	1.5 DS	90	1.1	Cracked through
100	2	1.5 CS	90	2.0	Scabbing
100	3	1.5 CS	90	1.1	Cracked through
100	4	1.5 CS	90	1.2	Cracked through
100	2	1.0 CS	90	2.0	Scabbing
100	3	1.0 CS	90	1.2	Cracked through
100	4	1.0 CS	90	1.1	No scabbing
100	2	2.0 CS	90	2.0	Scabbing
100	3	2.0 CS	90	1.1	No scabbing
100	4	2.0 CS	90	1.0	No scabbing
100	2	2.5 CS	90	2.0	Scabbing
100	3	2.5 CS	90	1.1	Cracked through

Table 4b (Cont)

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees)	Depth of Penetration (in.)	Comments
100	4	2.5 CS	90	1.3	No scabbing
100	2	3.0 CS	90	2.0	Scabbing
100	3	3.0 CS	90	1.1	Cracked through
100	4	3.0 CS	90	1.1	No scabbing
100	1	1.5 CS	15	0.1	No scabbing
100	1	1.0 CS	30	1.0	Scabbing
100	1	2.0 CS	30	1.0	Scabbing
100	2	1.5 CS	30	0.4	No scabbing
100	2	1.5 CS	45	0.9	Cracked through
100	3	1.5 CS	45	0.8	No scabbing
100	2	1.5 CS	60	2.0	Scabbing
100	3	1.5 CS	60	0.9	No scabbing
100	4	1.5 CS	60	0.9	No scabbing
100	2	1.5 CS	75	2.0	Scabbing
100	3	1.5 CS	75	1.1	No scabbing
100	4	1.5 CS	75	1.1	No scabbing
150	2	None	90	2.0	Scabbing
150	3	None	90	1.2	No scabbing
150	4	None	90	1.1	Cracked through
150	2	1.5 CS	90	2.0	Scabbing
150	3	1.5 CS	90	1.0	Cracked through
150	4	1.5 CS	90	1.1	No scabbing
200	2	None	90	2.0	Scabbing
200	3	None	90	3.0	Scabbing
200	2	1.5 CS	90	2.0	Scabbing
200	3	1.5 CS	90	1.1	Cracked through
200	4	1.5 CS	90	1.1	No scabbing

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel. DS denotes 1.016 x 1 in. drawn steel fibers from National Standard. FG denotes fiberglass fibers from Owens-Corning.

Table 4c

45-Caliber Pistol Plate Test Results

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees	Depth of Penetration (in.)	Comments
10	1	None	90	1.0	Scabbing
10	2	None	90	0.2	No scabbing
10	1	2.5 CS	90	0.1	No scabbing
20	2	None	90	0.1	No scabbing

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel.

Table 4d

50-Caliber Machine Gun Plate Test Results

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees)	Depth of Penetration (in.)	Comments
50	5	1.5 CS	90	5.0	Scabbing
50	6 (3 in. + 3 in.)	1.5 CS	90	3.7	No scabbing
50	7 (3 in. + 4 in.)	1.5 CS	90	3.4	No scabbing
50	7 (3 in. + 4 in.)	None	90	7.0	Scabbing
100	6	None	90	6.0	Shattered
100	4	1.5 CS	90	4.0	Scabbing
100	5	1.5 CS	90	5.0	Scabbing
100	6	1.5 CS	90	6.0	Scabbing
100	4	1.0 CS	90	4.0	Scabbing
100	4	2.0 CS	90	4.0	Scabbing
100	4	2.5 CS	90	4.0	Scabbing
100	4	3.0 CS	90	4.0	Scabbing
100	4	1.5 FG	90	4.0	Scabbing
100	5	1.5 FG	90	5.0	Scabbing
100	4	1.5 DS	90	4.0	Scabbing
100	5	1.5 DS	90	5.0	Scabbing
100	1	1.5 CS	15	1.0	Scabbing
100	2	1.5 CS	15	0.2	No scabbing
100	2	None	15	2.0	Scabbing
100	3	None	30	3.0	Scabbing
100	4	None	30	0.6	Cracked through
100	2	1.5 CS	30	2.0	Scabbing
100	3	1.5 CS	30	0.7	Cracked through
100	3	1.5 CS	45	3.0	Scabbing
100	4	1.5 CS	45	1.3	Scabbing
100	4	1.5 CS	60	4.0	Scabbing
100	5	1.5 CS	60	2.8	Cracked through
100	4	1.5 CS	75	4.0	Scabbing
100	5	1.5 CS	75	5.0	Scabbing
100	6 (3 in. + 3 in.)	1.5 CS	75	3.0	Slight crack through
150	6	None	90	6.0	Scabbing
150	5	1.5 CS	90	5.0	Scabbing
150	6	1.5 CS	90	3.6	No scabbing
200	6	None	90	6.0	Scabbing
200	5	1.5 CS	90	5.0	Scabbing
200	6	1.5 CS	90	3.1	Cracked through

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel. DS denotes 1.016 x 1 in. drawn steel fibers from National Standard. FG denotes fiberglass fibers from Owens-Corning.

Table 4e

20-mm Automatic Gun Plate Test Results

Range (yd)	Plate Thickness (in.)	Type of Fiber Reinforcement (percent)*	Angle of Impact (degrees)	Depth of Penetration (in.)	Comments
200	5	1.5 CS	90	5	Scabbing
200	2 in. + 4 in. air + 3 in.	1.5 CS	90	5	Scabbing
200	4	3.0 CS	90	4	Scabbing
200	4	1.5 CS	45	4	Scabbing

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel.

Table 5

M16 Rifle Penetration Depths vs. Fiber Content and Plate Thickness

Fiber Content (%)	Plate Thickness (in.) 2	3	4
0	2.0	0.7	1.1
1.0	0.9	0.9	0.9
1.5	0.9	0.9	0.8
2.0	1.0	0.8	0.9
2.5	0.8	0.7	0.8
3.0	0.8	0.8	0.7

Table 6

M16 Rifle Penetration Depths vs. Fiber Type and Plate Thickness

Type of Fiber (%)	Plate Thickness (in.) 2	3	4
None	2.0	0.7	1.1
1.5 CS*	0.9	0.9	0.8
1.5 DS	1.0	0.9	0.9
1.5 FG	0.9	1.0	1.1

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel. DS denotes 1.016 x 1 in. drawn steel fibers from National Standard. FG denotes fiberglass fibers from Owens-Corning.

Table 7

M16 Rifle Penetration Depths vs. Angle of Impact and Plate Thickness

Angle of Impact (degree)	Plate Thickness (in.) 1	2	3	4
15	0.1	—	—	—
30	0.4	0.4	0.3	—
45	—	0.6	0.6	0.6
60	—	0.7	0.6	0.8
75	—	0.8	0.9	0.9
90	—	0.9	0.9	0.8

Table 8

M16 Rifle Penetration Depths vs. Range and Plate Thickness

Range (yd)	0% Fiber Plate Thickness (in.) 2	3	4	1.5% CS* Plate Thickness (in.) 1	2	3	4
50	2.0	1.1	1.0	—	1.0	0.9	0.9
100	2.0	0.7	1.1	—	0.9	0.9	0.8
150	2.0	0.7	—	1.0	0.9	0.8	—
200	0.8	0.8	—	—	0.6	0.8	—

*0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel.

Table 9

30-Caliber Machine Gun Penetration Depths vs. Fiber Content and Plate Thickness

Fiber Content (%)	Plate Thickness (in.) 2	3	4	5
0	2.0	3.0	1.3	1.3
1.0	2.0	1.2	1.1	—
1.5	2.0	1.1	1.2	—
2.0	2.0	1.1	1.0	—
2.5	2.0	1.1	1.3	—
3.0	2.0	1.1	1.1	—

Table 10

30-Caliber Machine Gun Penetration Depths vs. Fiber Type and Plate Thickness

Type of Fiber (%)	Plate Thickness (in.) 2	3	4
None	2.0	3.0	1.3
1.5 CS*	2.0	1.1	1.2
1.5 DS	2.0	1.2	1.1
1.5 FG	2.0	1.4	1.3

*CS denotes 0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel. DS denotes 1.016 x 1 in. drawn steel fibers from National Standard. FG denotes fiberglass fibers from Owens-Corning.

Table 11

30-Caliber Machine Gun Penetration Depths vs. Angle of Impact and Plate Thickness

Angle of Impact (degrees)	Plate Thickness (in.) 1	2	3	4
15	0.1	—	—	—
30	—	0.4	—	—
45	—	0.9	0.8	—
60	—	2.0	0.9	0.9
75	—	2.0	1.1	1.1
90	—	2.0	1.1	1.2

Table 12

30-Caliber Machine Gun Penetration Depths vs. Range and Plate Thickness

Range (yd)	0% Fiber Plate Thickness (in.) 2	3	4	5	1.5% CS* Plate Thickness (in.) 2	3	4
50	2.0	3.0	1.3	1.3	2.0	1.2	1.3
100	2.0	3.0	1.3	1.3	2.0	1.1	1.2
150	2.0	1.2	1.1	—	2.0	1.0	1.1
200	2.0	3.0	—	—	2.0	1.1	1.1

*0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel.

Table 13

50-Caliber Machine Gun Penetration Depths vs. Fiber Content and Plate Thickness

Fiber Content (%)	Plate Thickness (in.) 4	5	6
0	—	—	6.0
1.0	4.0	—	—
1.5	4.0	5.0	6.0
2.0	4.0	—	—
2.5	4.0	—	—
3.0	4.0	—	—

Table 14

50-Caliber Machine Gun Penetration Depths vs. Fiber Type and Plate Thickness

Type of Fiber (%)	Plate Thickness (in.) 4	5	6
None	—	—	6.0
1.5 CS	4.0	5.0	6.0
1.5 DS	4.0	5.0	—
1.5 FG	4.0	5.0	—

Table 15

30-Caliber Machine Gun Penetration Depths vs. Angle of Impact and Plate Thickness

Angle of Impact (degrees)	Plate Thickness (in.) 1	2	3	4	5	6(3 in. + 3 in.)
15	1.0	0.2	—	—	—	—
30	—	2.0	0.7	—	—	—
45	—	—	3.0	1.3	—	—
60	—	—	—	4.0	2.8	—
75	—	—	—	4.0	5.0	—
90	—	—	—	—	5.0	3.0

Table 16

30-Caliber Machine Gun Penetration Depths vs. Range and Plate Thickness

Range (yd)	0% Fiber Plate Thickness (in.) 3	4	5	6	7	1.5% CS* Plate Thickness (in.) 4	5	6	7
50	—	—	5.0	6.0	7.0	—	5.0	3.7	3.4
100	—	—	—	6.0	—	4.0	5.0	6.0	—
150	—	—	—	6.0	—	—	5.0	3.6	—
200	—	—	—	6.0	—	—	5.0	3.1	—

*0.01 x 0.22 x 1 in. chopped steel fibers from U.S. Steel.

Figure 1. M16 rifle.

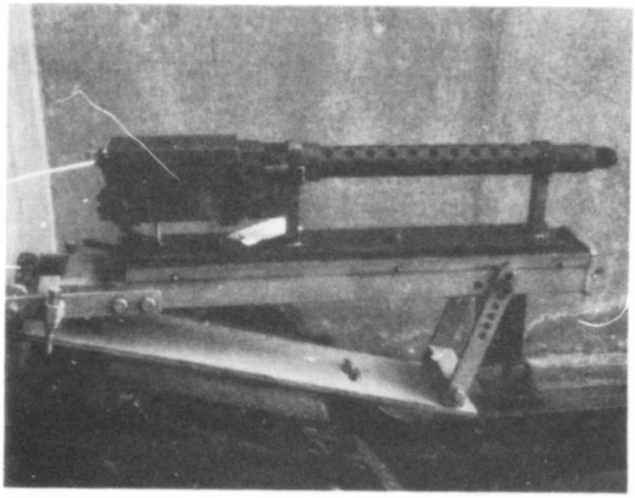


Figure 2. M73 30-caliber machine gun.

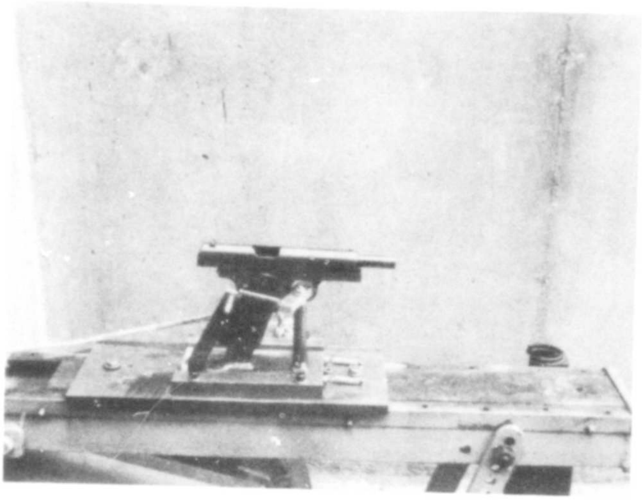


Figure 3. 45-caliber pistol.

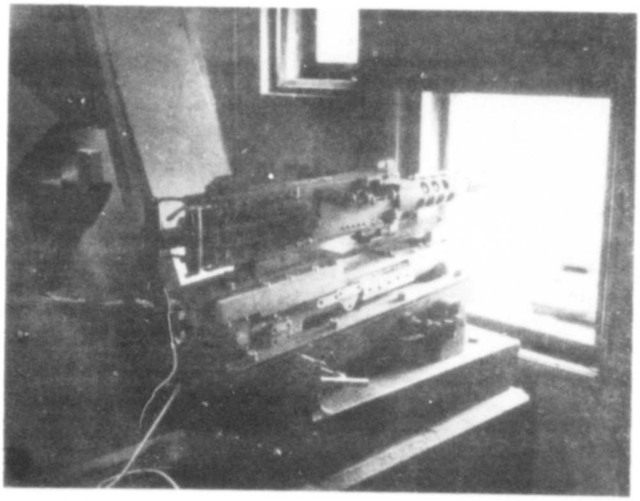


Figure 4. 50-caliber machine gun.

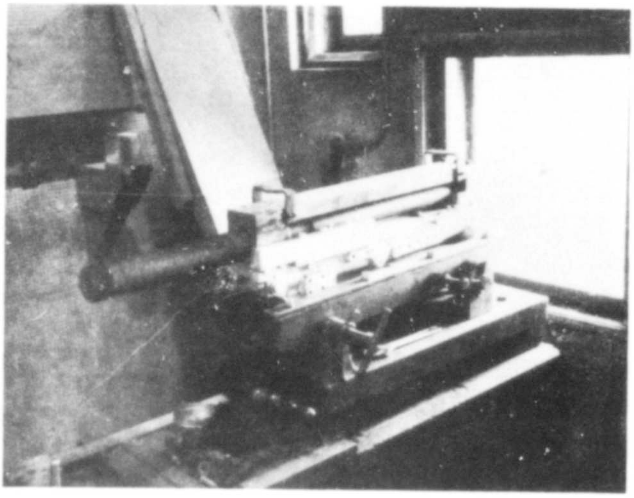


Figure 5. 20-mm automatic gun.

Figure 6. 81-mm mortar.

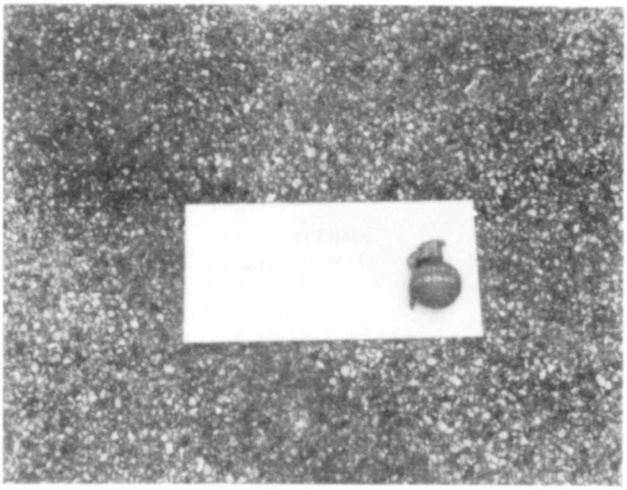


Figure 7. M67 fragmentation grenade.

Figure 8. View of three domes tested.

Figure 9. 81-mm mortar in firing position adjacent to dome.

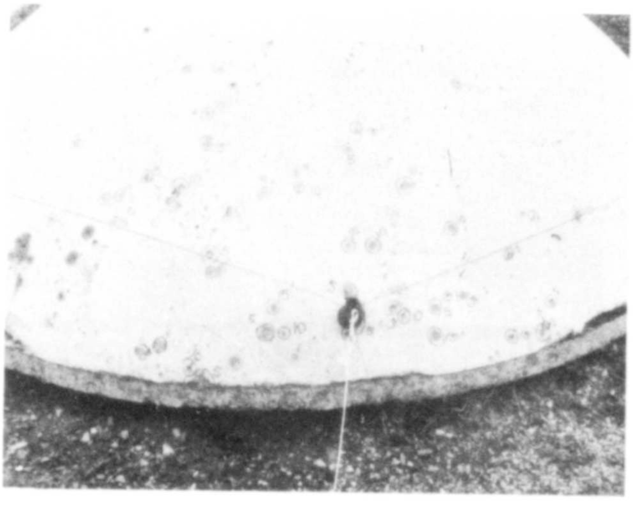


Figure 10. Pitting resulting from detonation of M67 grenades at 15, 10, and 5 ft.

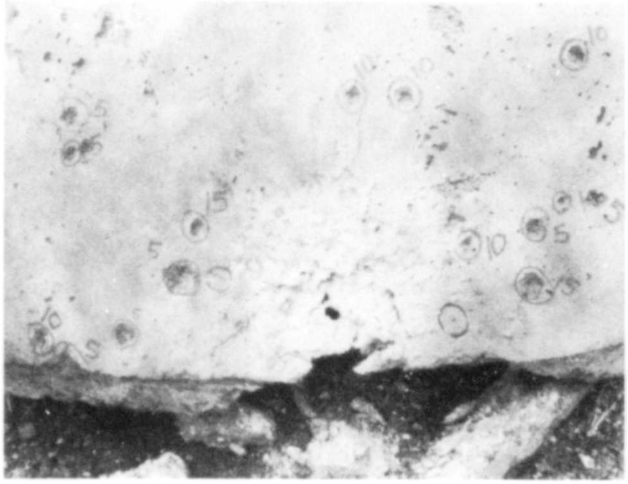


Figure 11. Damage from M67 grenade exploded on surface of dome.

Figure 12. Damage from M67 grenade exploded inside dome.

Figure 13. Cumulative damage on 6-in. dome from 81-mm mortars detonated at 5, 10, and 15 ft.

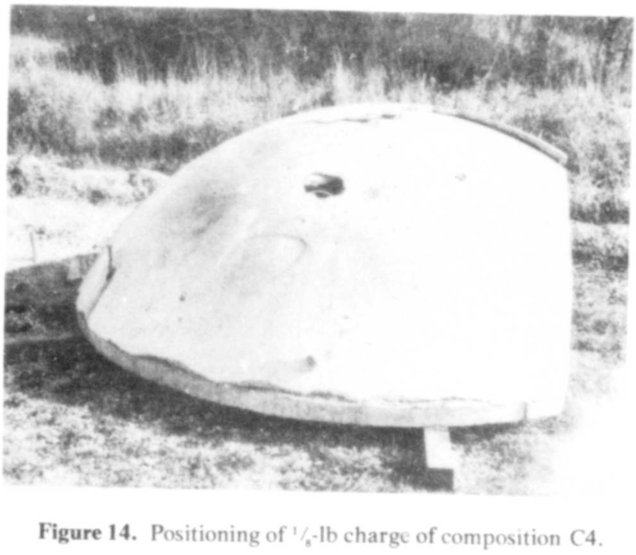


Figure 14. Positioning of $^1/_8$-lb charge of composition C4.

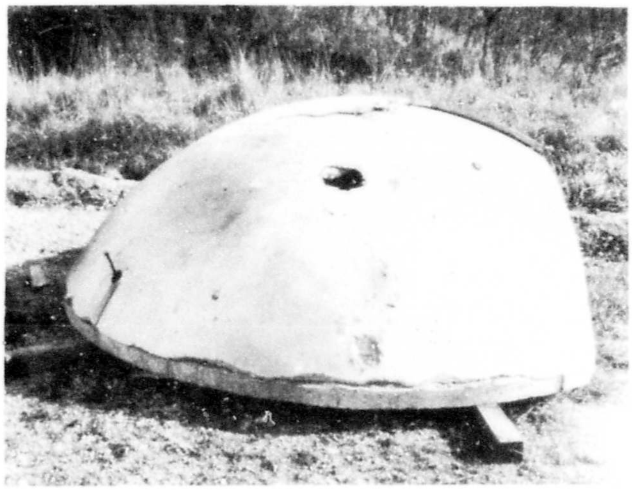


Figure 15. Damage resulting from $^1/_8$-lb charge of C4.

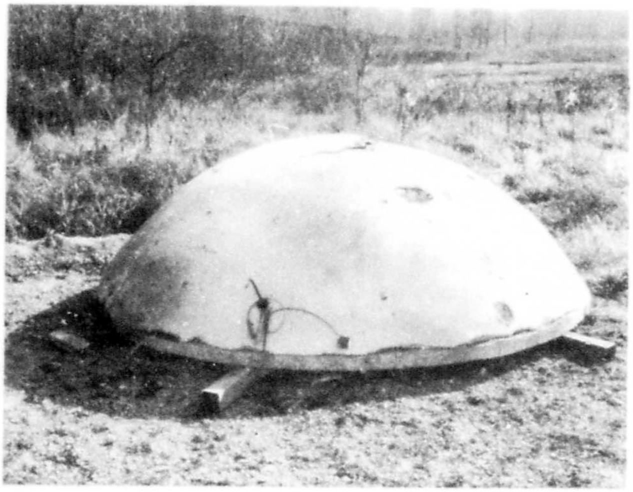


Figure 16. Positioning of ¼-lb charge of composition C4.

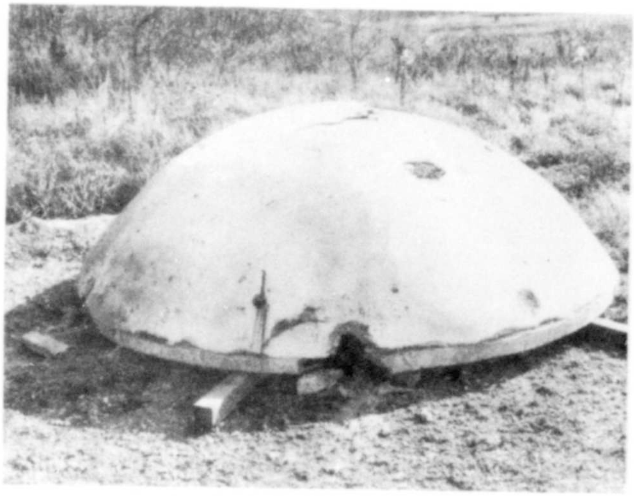


Figure 17. Damage resulting from ¼-lb charge of C4.

Figure 18. 4½-in. nominal thickness dome and portion of 6-in.-thick dome used for 50-caliber and 20-mm tests.

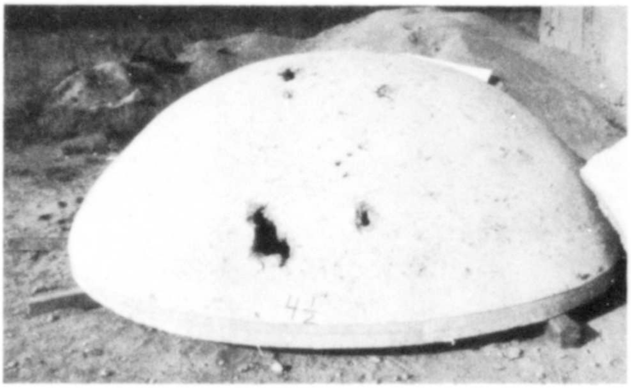


Figure 19. Results of several firings of 50-caliber machine gun at the 4½-in. nominal thickness dome.

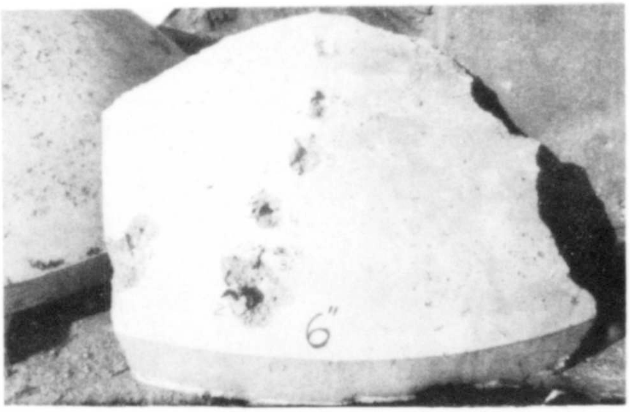


Figure 20. Effects of 50-caliber machine gun on segment of a 6-in.-thick dome.

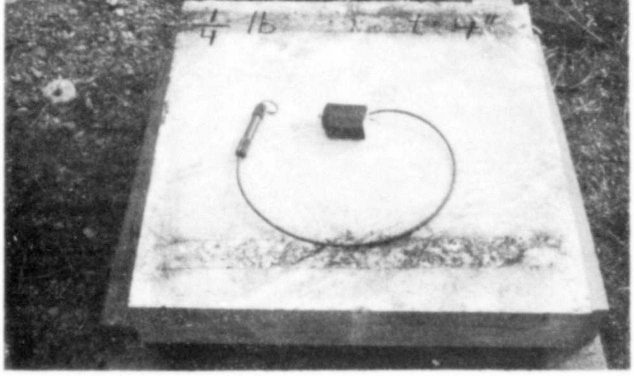


Figure 21. Arrangement for testing plates with high explosives.

Figure 22a. Donor side of 4-in. plate subjected to $^1/_8$-lb charge of C4.

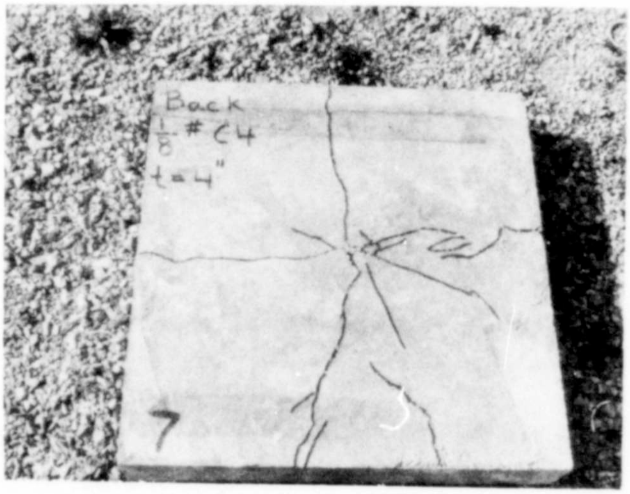


Figure 22b. Acceptor side of plate shown in Figure 22a.

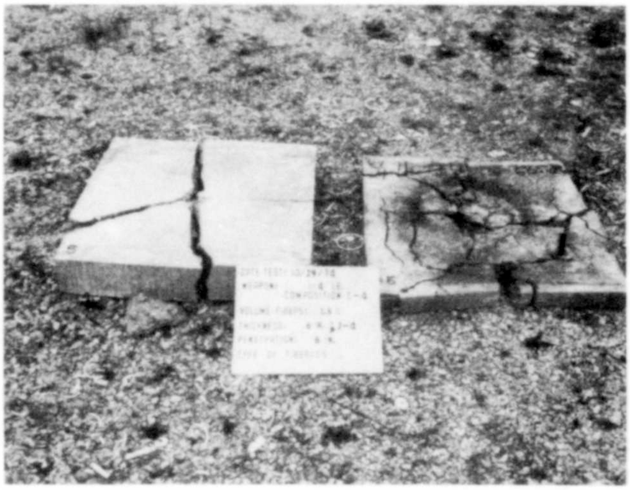


Figure 23. Donor and acceptor sides of 6-in. plate subjected to ¼-lb charge of C4.

Figure 24. Arrangement for testing plate specimens for resistance to small arms fire.

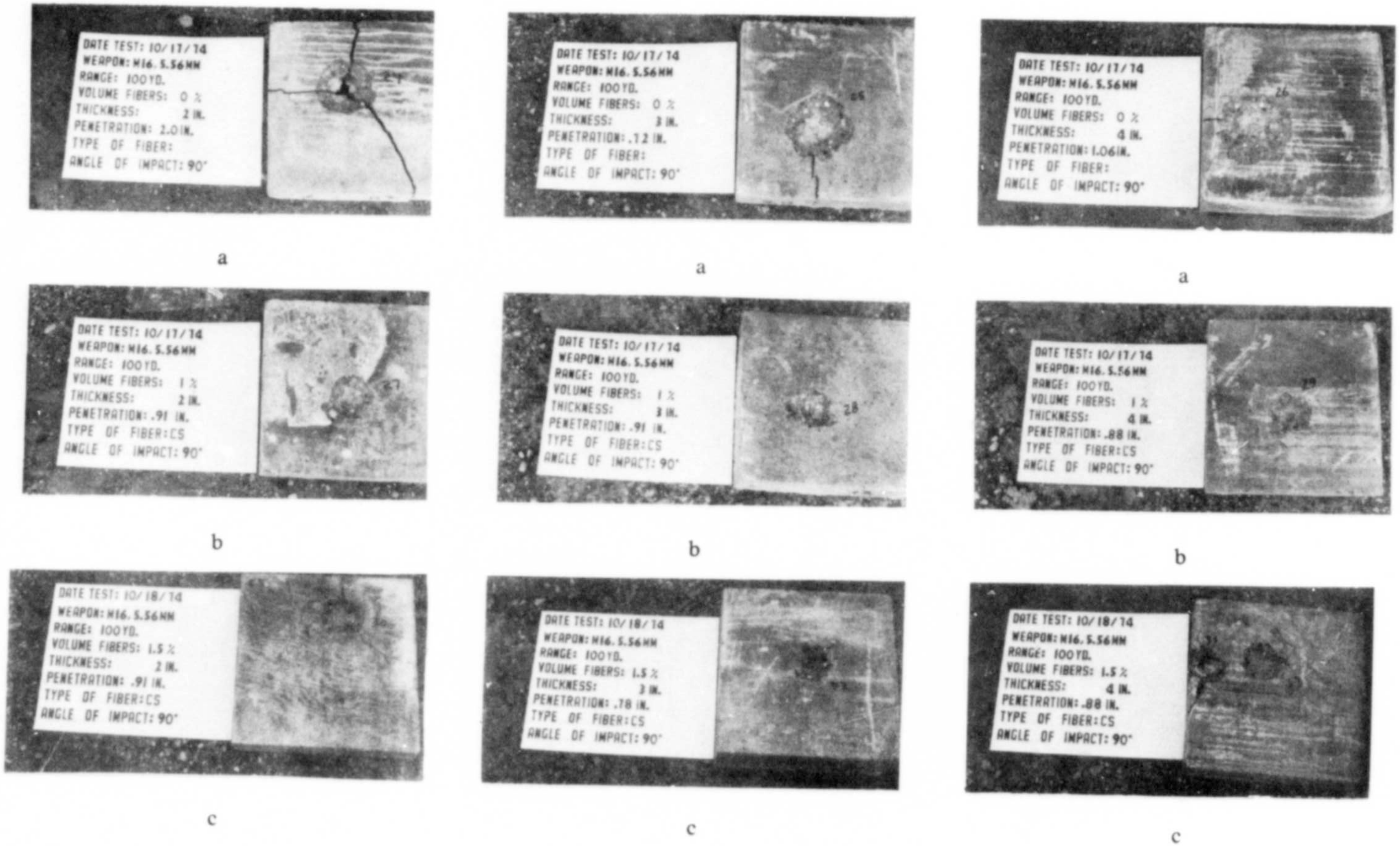
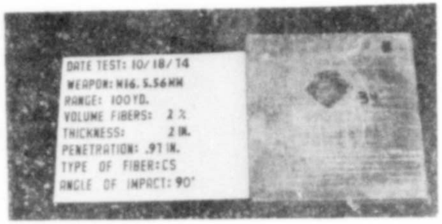


Figure 25. Effect of M16 rifle on plates of varying thicknesses and fiber contents.



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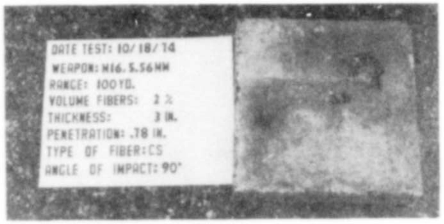

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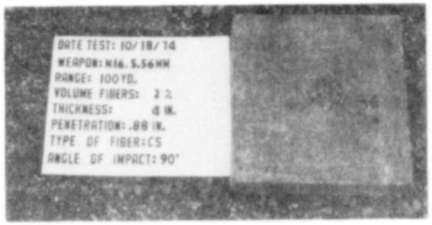

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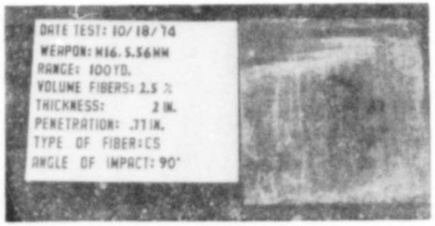

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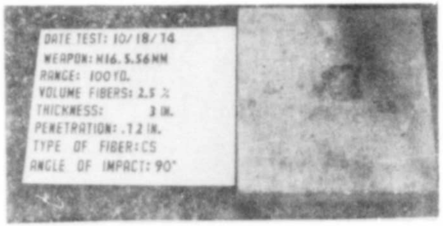

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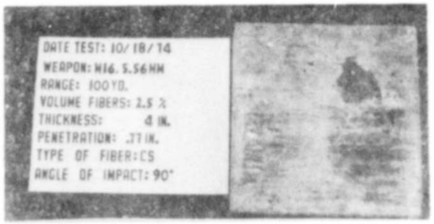

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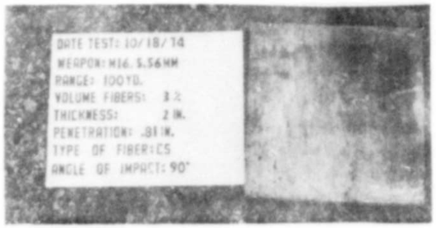

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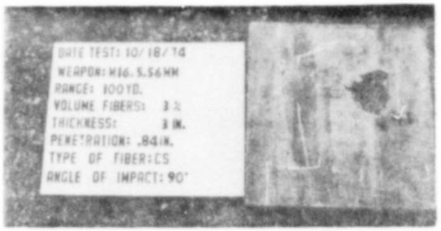

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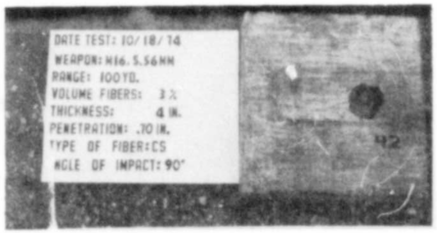

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Figure 25. (cont).

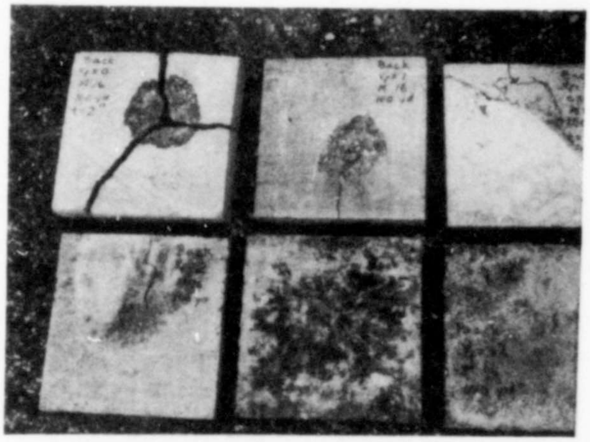


Figure 26. Comparison of scabbing in 2-in.-thick plates containing fiber contents of 0 to 3 percent. The weapon used was the M16 rifle with a 5.56 mm projectile.

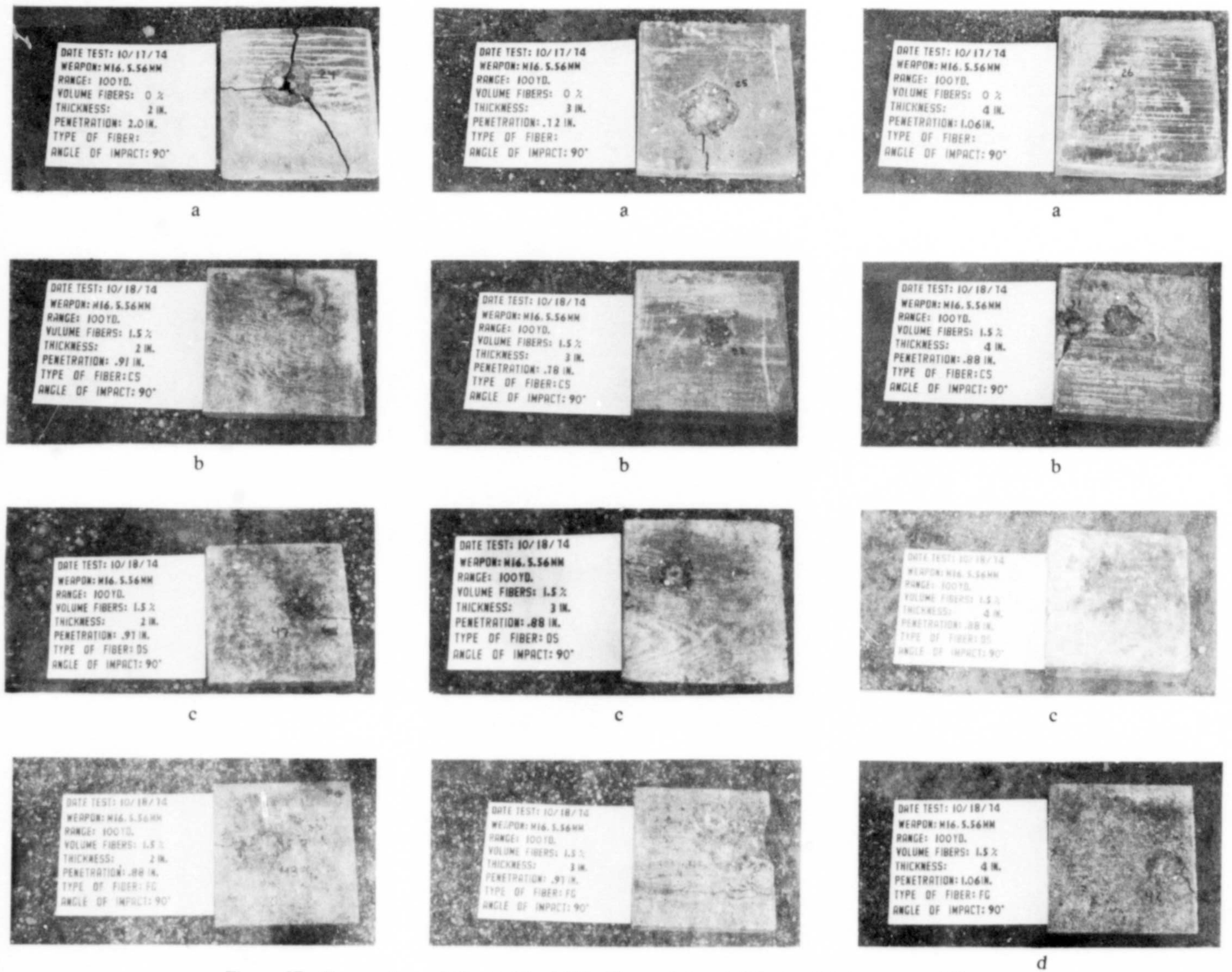


Figure 27. Comparison of effect of the M16 rifle on plates of differing thicknesses and fibers.

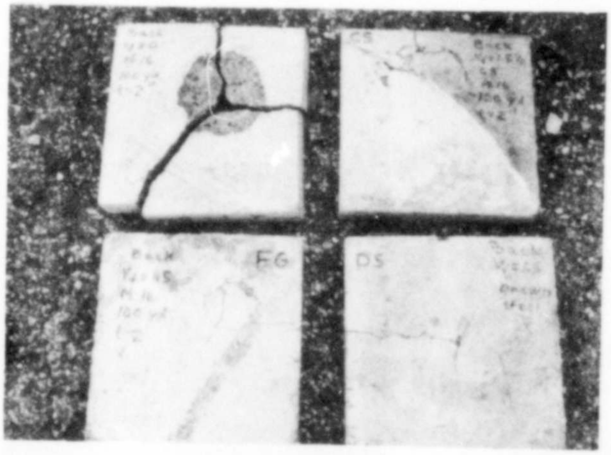


Figure 28. Comparison of scabbing for 2-in.-thick fiber- and nonfiber-reinforced plates.

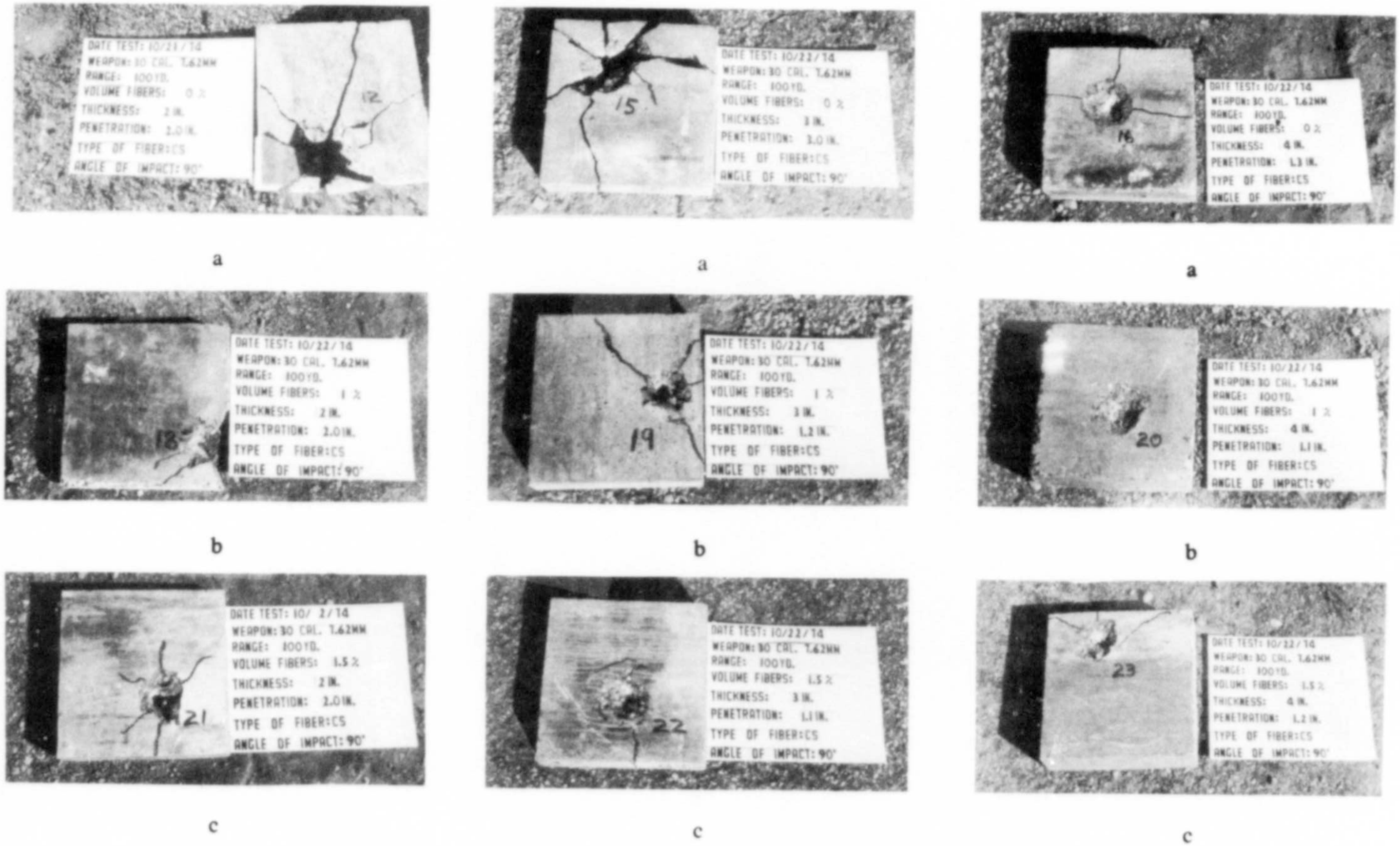
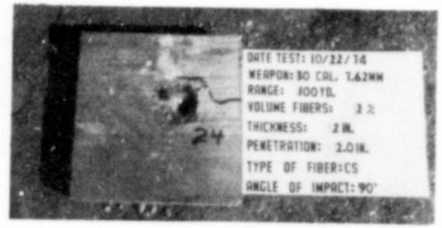


Figure 29. Effects of the 30-caliber machine gun on plates of varying thicknesses and fiber percentages.



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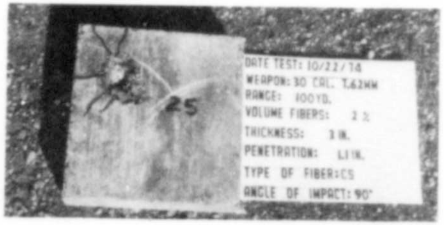

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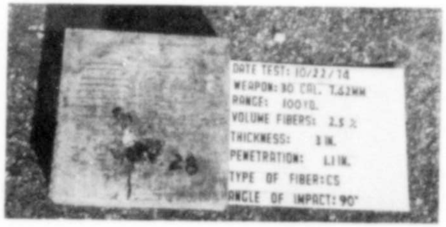

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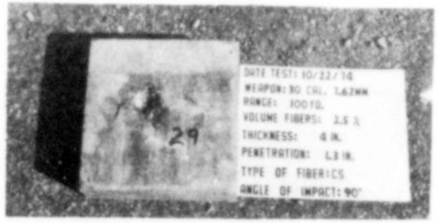

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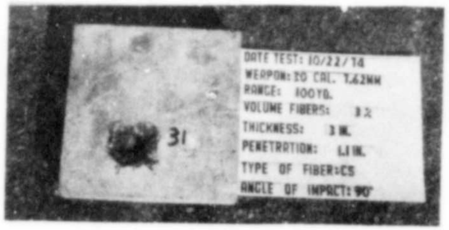

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Figure 29. (cont).

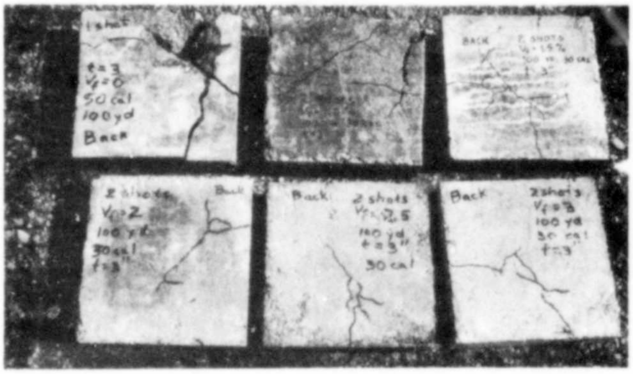

Figure 30. Comparison of scabbing from 30-caliber machine gun projectiles on 3-in. plates with fiber contents from 0 to 3 percent.

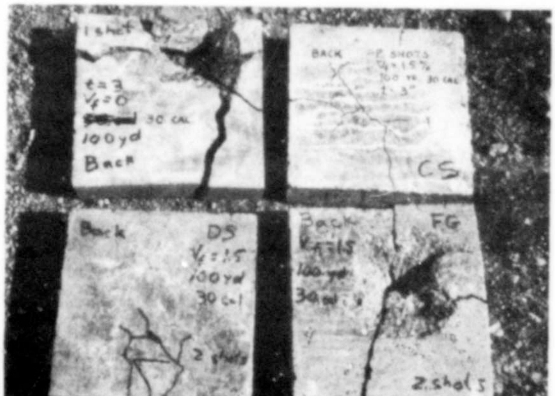

Figure 31. Scabbing from a 30-caliber machine gun of 3-in. plates with differing fibers.

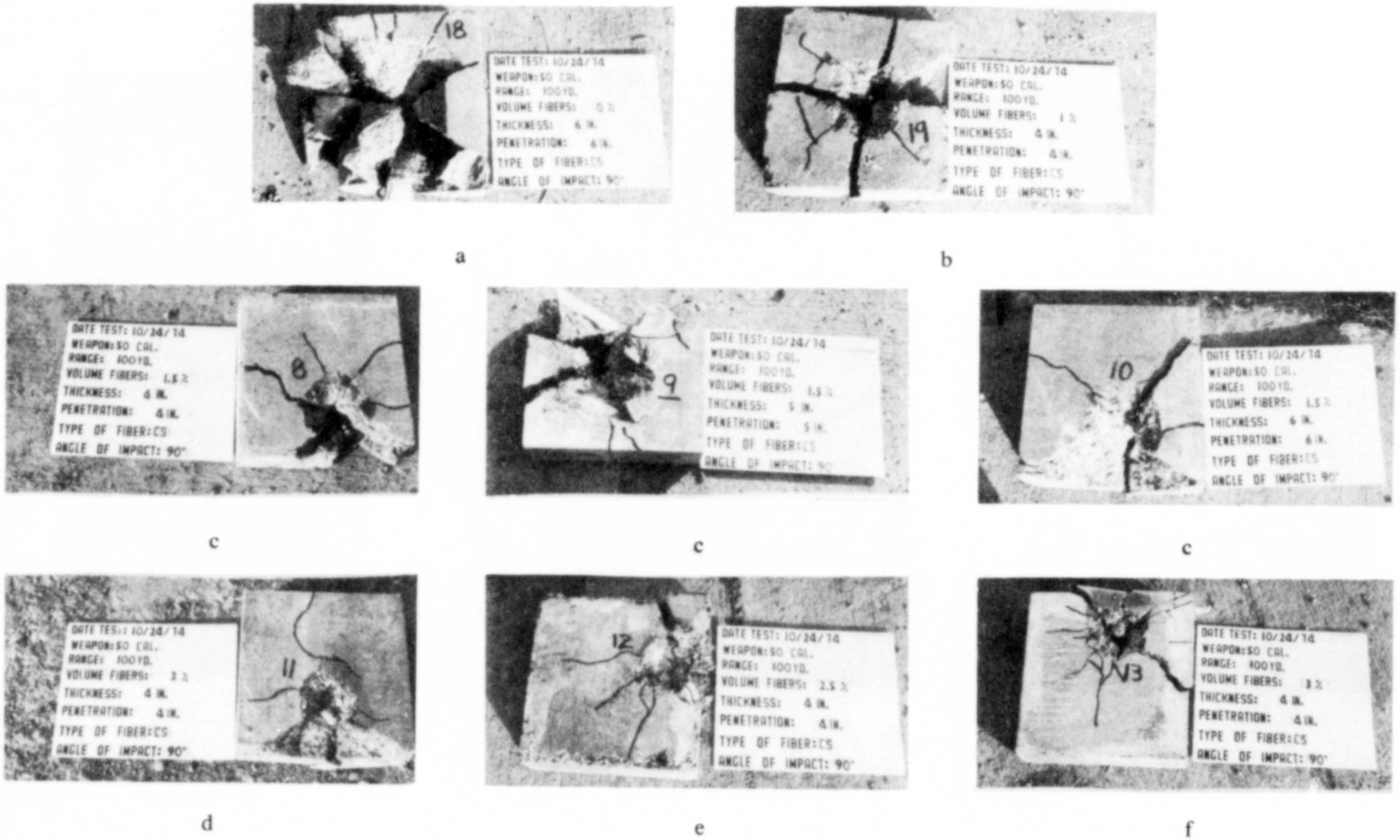

Figure 32. Effect of fiber content and plate thickness on resistance to penetration from 50-caliber machine gun projectiles.

Figure 33. Effect of a 20-mm projectile on a 5-in. plate at 200 yds.

Figure 34. Effect of a 20-mm projectile on two 3-in. plates with a 4-in. space between them.

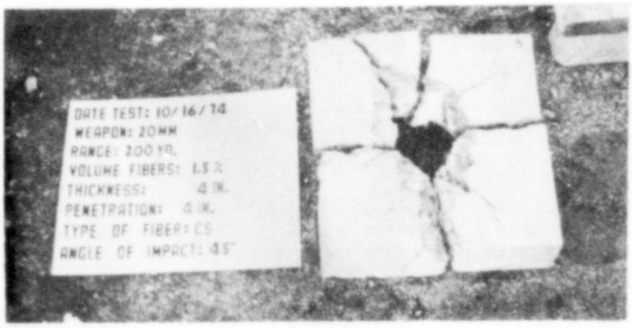

Figure 35. Effect of a 20-mm projectile on a 4-in. plate at impact angle of 45°.

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